Hampton Bay
Tide Gauge
Hampton, NH

Draft 2.1

Tidal DATUM analysis

Prepared for:
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1. Site Description and Equipment Installation

A tide gauge sensor comprised of a microwave radar transducer and a cellular telemetry unit was placed in Hampton Bay, NH, at approximately 42°54’00.3 N, 70°49’07.1W. The tide gauge was installed on a piling with the sensor transducer pointed down towards the water. The 26GHz (K-band) microwave radar sensor collects distance to water measurements (a.k.a. Ullage) with a stated accuracy of ±0.08 inch (±2 mm) (Make Endress & Hauser FMR51[1]). The gauge is scheduled to read the water level ever 6 minutes continuously using the NOAA Protocol[2]. Data collection was initiated on December 12th, 2014, and is ongoing.

The original deployment, or Gauge 1, was taken offline on February 8th, 2016, due to data collection issues. At the position of Gauge 1, certain Low Water Levels would cause the area directly beneath the sensor to go dry. Because of this, the gauge was moved to a second location, deemed Gauge 2, and began data collection on November 8, 2016. Around January of 2022, Gauge 2 began to show increased rates of errors, with a total failure of the telemetry unit in June of that year. Due to the increased error rate, data collected after January of 2022 by Gauge 2 were not included in the tidal datum calculations. A replacement telemetry unit (Onset Computers RX3000 4G telemetry) was installed on July 6, 2022, which started data collection of Gauge 3.

[1] Endress & Hauser FMR51 26GHz Microwave Radar
https://bdih-download.endress.com/files/DLA/005056A500261EDAB3AE2266BFE11B4D/TI01040FEN_1020.pdf

[2] NOAA Protocol for water level: average of 181 samples collected at 1s interval with outlier rejection of points greater than two times the Standard Deviation.

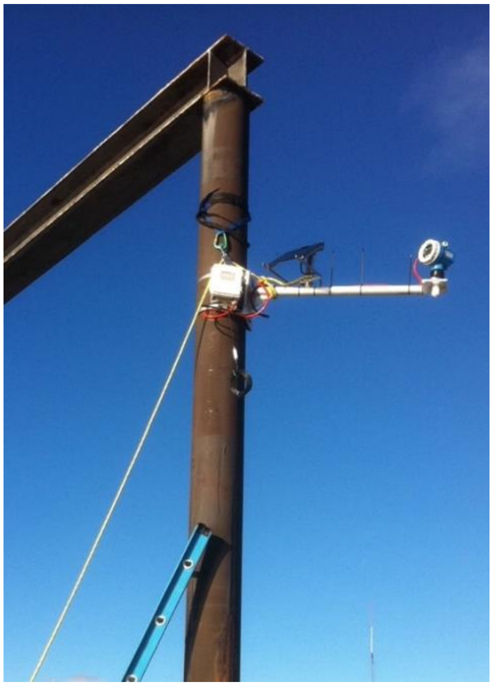


FIGURE 1: ORIGINAL TIDE GAUGE LOCATION (GAUGE 1)

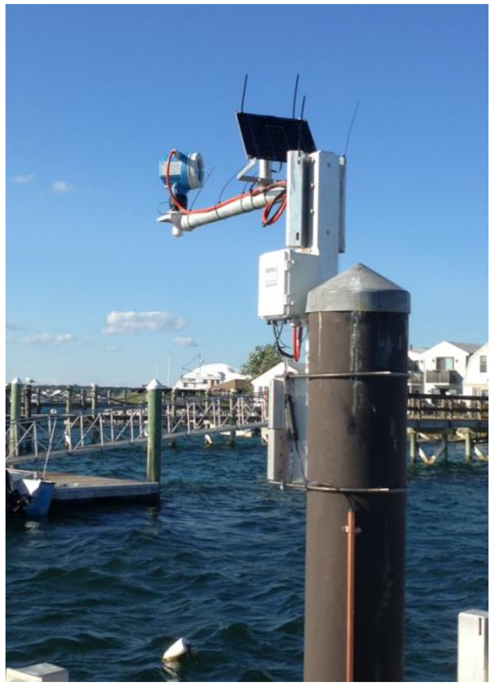


FIGURE 2: NEW TIDE GAUGE LOCATION (GAUGE 2, AND 3)

2. WATER LEVEL REFERENCE AND ELEVATION SURVEY

By knowing the elevation of the gauge relative to a common vertical reference datum (such as the North American Vertical Datum of 1988, or NAVD88) and the measured distance to water (Ullage), water level relative to NAVD88 can be calculated by the formula:

$$WaterLevel_{NAVD88} = GaugeElevation_{NAVD88} - Ullage$$

By relating the water level to a common vertical reference datum, such as the NAVD88, the water elevation levels from this gauge can be compared to all other tide gauges (as well as many other datasets) that have been tied into this vertical reference datum.

The elevation of the tide gauge was measured by using a Trimble R12 Real-Time Kinematic (RTK) GPS[A]. The use of this system when compared to known benchmarks yields an average error of 0.315 inches (0.008 m) horizontally and 0.236 inches (0.006 m) vertically (Borrelli, et al., 2022[3]).

[3] Borrelli, M., Smith, T. L., & Mague, S. T. (2022). Vessel-based, shallow water mapping with a phase-measuring sidescan sonar. *Estuaries and Coasts*, *45*(4), 961-979.

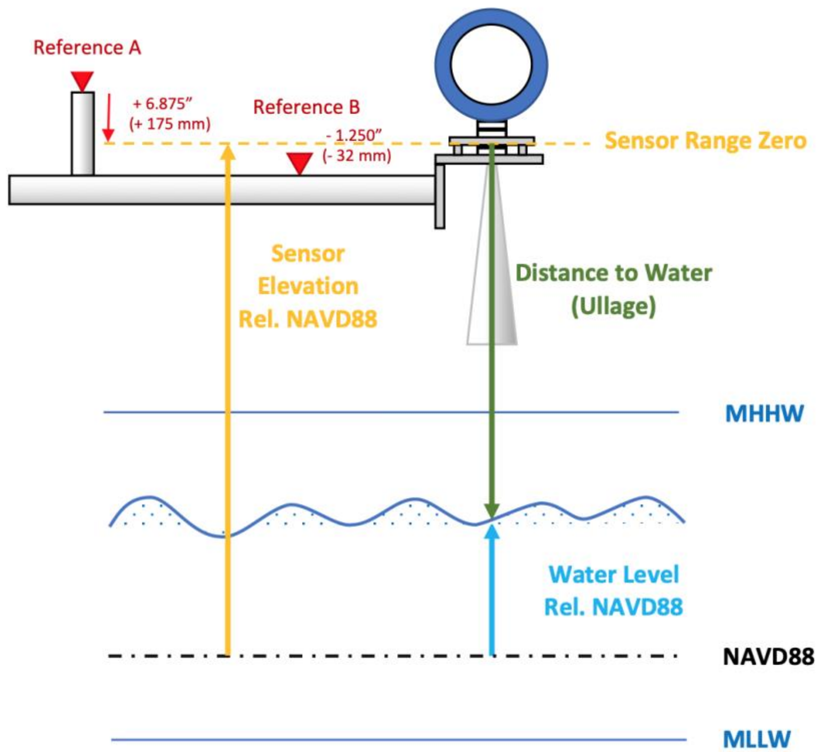


FIGURE 3: TIDE GAUGE RELATIVE ELEVATION SCHEME.

3. DATA PREPARATION

To prepare the data for use with the NOAA CO-OPS Tidal Analysis Datum Calculator, periods of usable data ranging from a month to a year from all three of the gauges were extracted, totaling 13 sampling periods. Each of these sampling periods was then individually filtered using an algorithm that removed any outliers in the data that fell outside of ±3 times the standard deviations of the mean from that dataset. However, the NOAA tool requires continuous datasets, thus the removed outlier values were replaced with sinusoidally interpolated values. A second filter was then run on the datasets to determine the semi-diurnal amplitudes of the main harmonic component of the tidal data; data points were then compared with pure harmonic oscillations at the predetermined amplitudes and those found outside ±10% of the harmonic value were replaced by sinusoidal interpolation. A portion of one of the sampling periods is displayed below.

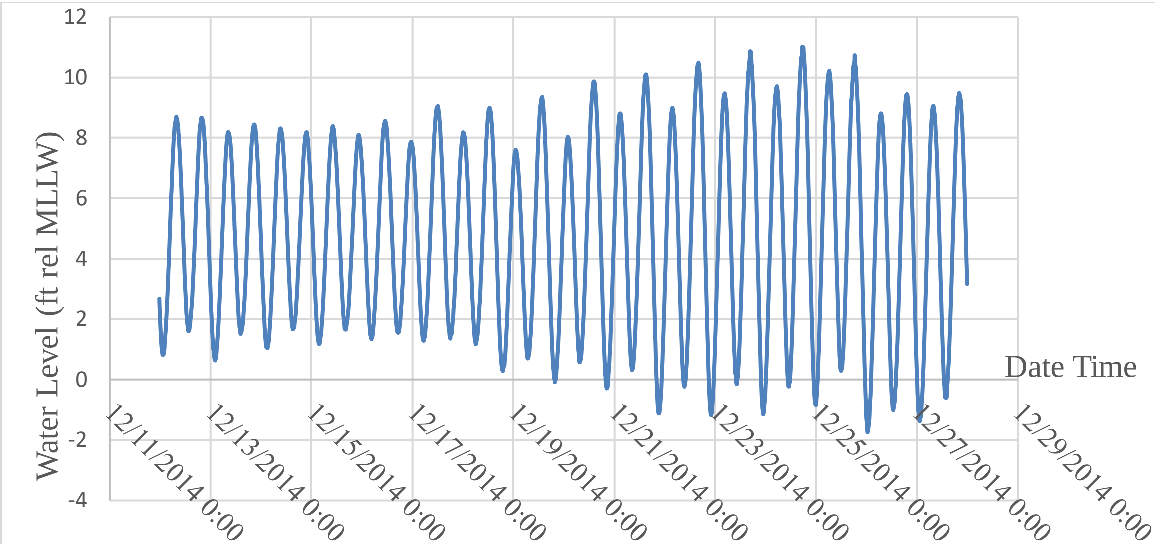


FIGURE 4: PORTION OF FILTERED TIDAL DATA

Below is the list of the data periods that were selected and filtered in preparation for the NOAA CO-OPS Tidal Analysis Datum Calculator,

Table 1: **Selected tidal data for datum calculation**

START DATE	END DATE	APPROX. DURATION	GAUGE	WEIGHT (1 – 6)
12/12/14	12/27/14	2 weeks	Gauge 1	1
1/1/15	12/31/15	Year	Gauge 1	4
1/1/16	2/8/16	1 Month	Gauge 1	3
11/8/16	12/31/16	1.5 Months	Gauge 2	3
1/6/17	12/31/17	1 Year	Gauge 2	4
1/1/18	12/31/18	1 Year	Gauge 2	5
1/1/19	6/4/19	6 Months	Gauge 2	5
1/1/20	12/31/20	1 Year	Gauge 2	6
1/1/21	7/24/21	8 Months	Gauge 2	6
8/24/21	12/31/21	4 Months	Gauge 2	6
7/6/22	10/26/22	3 Months	Gauge 3	5

4. NOAA CO-OPS Tidal Analysis Datum Calculator

The Center for Operational Oceanographic Products and Services (CO-OPS), through the National Oceanographic and Atmospheric Association (NOAA), provide access to a service which calculates tidal datums based on input data, called Tidal Analysis Datum Calculator. This tool takes tidal data with a datetime stamp and level and calculates levels for key tidal metrics such as Mean Higher High Water (MHHW), Mean High Water (MHW), Mean Sea Level (MSL), Mean Low Water (MLW), Mean

Lower Low Water (MLLW), and more. For additional information on how this service functions, a full Technical Report[4] can be found on the NOAA CO-OPS website.

The 13 selected datasets were entered as input to the calculator. The datums produced where averaged giving different weights based on the data quality score, the length, and age of the of the submitted datasets. We used the calculator without and with two nearby control stations. Although utilizing control stations ties the local datum to the National Tidal Datum Epoch (NTDE), we believe that in doing so we underestimate water level at Hampton Bay. The reason for this is, we believe, that the control stations used (8419870 Seavey Island, ME, and 8443970 Boston, MA) have datums based on the 1983 – 2001 Epoch, which is the current Tidal Epoch centered around 1992, while the data from the Hampton Bay Tide Gauge is centered around 2020 (based on the weighted average); this means that approximately 28 years of Sea Level Rise are not taken into account. Depending on different estimates of SLR, this could mean that MLLW at the control stations is underestimated by anywhere from 0.180ft to 0.320ft. The specific location of the Hampton Bay Tide Gauge also plays an important role in determining the local tidal conditions. The resulting datums are reported in the table below along with typical representations one might find on a NOAA Tides & Currents Datum page (figures 5, and 6 below).

TABLE 2: TIDAL DATUMS FOR HAMPTON BAY

Datum[5]	**Standalone** Period 2014-2022		**With Control Station: 8419870 Seavey Island, ME** Epoch 1983-2001		**With Control Station: 8443970 Boston, MA** Epoch 1983-2001	
	Elevation, ft (MLLW)	Elevation, ft (NAVD88)	Elevation, ft (MLLW)	Elevation, ft (NAVD88)	Elevation, ft (MLLW)	Elevation, ft (NAVD88)
MHHW	9.488	4.821	9.470	4.445	9.480	4.295
MHW	9.083	4.416	9.050	4.025	9.070	3.885
MTL	4.712	0.045	4.690	-0.335	4.700	-0.485
DTL	4.744	0.077	4.730	-0.295	4.740	-0.445
MSL	4.790	0.123	4.770	-0.255	4.780	-0.405
MLW	0.341	-4.326	0.340	-4.685	0.320	-4.865
MLLW	**0.000**	**-4.667**	0.000	-5.025	0.000	-5.185
NAVD88	**4.667**	**0.000**	5.025	0.000	5.185	0.000
DHQ	0.406	0.406	0.420	0.420	0.410	0.410
DLQ	0.341	0.341	0.340	0.340	0.320	0.320
MN	8.742	8.742	8.710	8.710	8.750	8.750
GT	9.448	9.448	9.470	9.470	9.490	9.490

[4] https://access.co-ops.nos.noaa.gov/datumcalc/docs/TechnicalReport.pdf
[5] https://tidesandcurrents.noaa.gov/datum_options.html

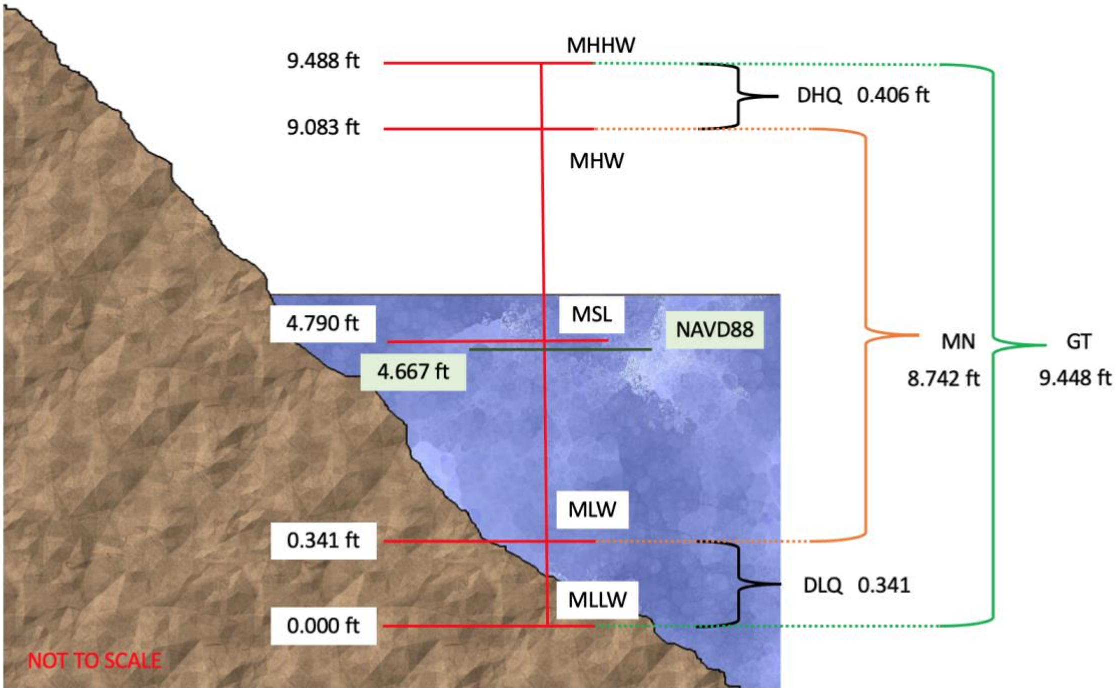


FIGURE 5: TIDAL DATUMS FOR HAMPTON BAY ILLUSTRATED (NOT TO SCALE)

The Hampton Tide Gauge is currently reporting water level relative to MLLW. This is commonly preferred for tide gauges from the mariner's perspective. Landward however, it is preferred to report water level relative to NAVD88, because most infrastructure is referenced to NAVD88, and it is more immediate to understand the risk of flooding. From our analysis, MLLW at Hampton Bay is 4.667ft below the NAVD88 vertical reference datum (or -4.667ft relative NAVD88).

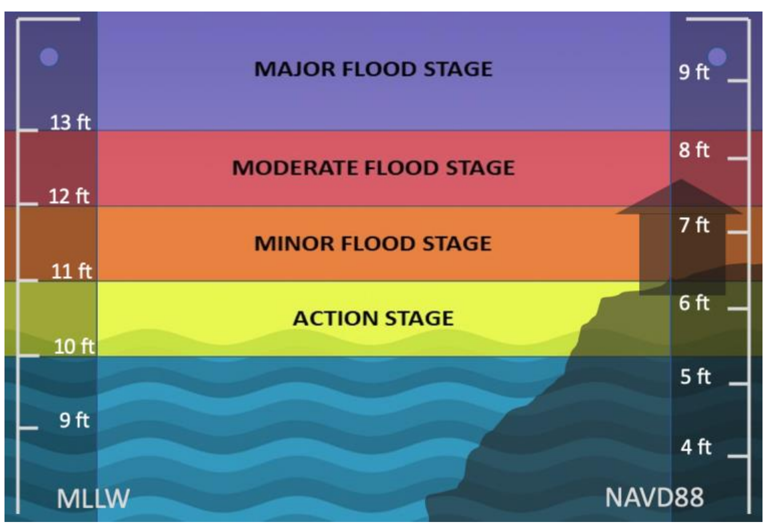


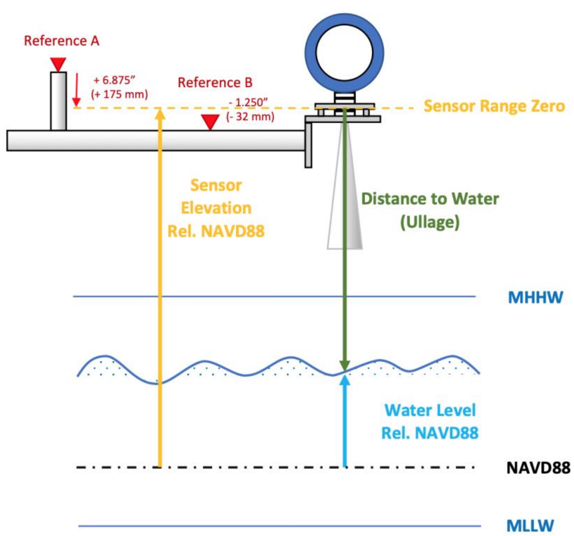
FIGURE 6: FLOOD CATEGORIES FOR HAMPTON, NH, REFERENCED TO MLLW (NATIONAL WEATHER SERVICE ADVANCED HYDROLOGIC PREDICTION SERVICE, CREDIT: RAYANN DIONNE), WITH ADDED APPROXIMATE NAVD88 SCALE AND TERRESTRIAL FEATURES FOR DRAMATIC EFFECT.

[A] Appendix A: RTK Survey of Tide Gauge Elevation November 4, 2022

The elevation survey was performed on November 4, 2022, at approximately 9:15AM. A Trimble R12 RTK receiver was held in 2 reference positions on the boom that supports the Microwave Radar transducer. At each position, we collected 3 separate elevation observations (named: HB_tide_sensor_01, 02, 03 for reference position A, and HB_tide_sensor_04, 05, 06 for reference position B). The vertical offsets between the observation points and the Radar transducer were measured with a ruler with precision of ±1/32” (or ±0.003ft). The estimated parallax error on the offset reading was ±0.003ft. The reported vertical elevation uncertainty was ±1.2cm, or 0.039ft. The maximum vertical error of each reading was therefore estimated as the sum of the ruler precision + the parallax error + the vertical uncertainty, or ±0.045ft (or ±1.4cm). All observations were reduced to the radar elevation by applying the offsets, and then averaged to obtain the elevation of the Radar Transducer (relative to NAVD88).

Job: Hampton_Bay survey 2022_11_04	*Elevation (m) NAVD88*	*Elevation (ft) NAVD88*	*offset to sensor (ft)*	*Corrected Elev. (ft) NAVD88*	*Avg. Elevation (ft) NAVD88*
HB_tide_sensor_01	4.470	14.665	-0.607	14.058	**14.050**
HB_tide_sensor_02	4.469	14.662	-0.607	14.055	
HB_tide_sensor_03	4.464	14.646	-0.607	14.039	
HB_tide_sensor_04	4.253	13.953	0.104	14.057	
HB_tide_sensor_05	4.248	13.937	0.104	14.041	
HB_tide_sensor_06	4.251	13.947	0.104	14.051	

Tide Gauge elevation = 14.050 ± 0.045ft relative NAVD88 (4.282 ± 0.014 m)



Spot check: Ullage = 123.5” @9:27AM on 11/4/’22, corresponding to WL_{MLLW} = 8.614’
From data on Hobolink.com on 11/4/’22: @9:24AM WL_{MLLW} = 8.656’,
@9:30AM WL_{MLLW} = 8.565’, @9:27AM WL_{MLLW} ~ 8.611’ → Error = 0.003’

Appendix B: RTK Survey of Tide Gauge Elevation June 21, 2024

Job: Hampton_Bay survey 2024_06_21	*Occupation time*	*Elevation (m) NAVD88*	*Elevation (ft) NAVD88*	*offset to sensor (ft)*	*Elevation (ft) NAVD88*
HB_long-A_01	2h	4.474	14.678	-0.607	14.071
HB_long-B_02	2h	4.270	14.009	0.104	14.115
AVERAGE					**14.093**

Tide Gauge elevation = 14.093 ± 0.045ft relative NAVD88 (4.295 ± 0.014 m)